UNIT-II

FLOW MEASUREMENT

Accurate measurement of flow rate of liquids and gases is an essential requirement for maintaining the quality of industrial processes. Most of the industrial control loops control the flow rates of incoming liquids or gases in order to achieve the control objective. As a result, accurate measurement of flow rate is very important.

There are different types of flow measuring techniques that are used in industries. The common types of flowmeters that find industrial applications can be listed as below:

(a) Obstruction type (differential pressure or variable area)

(b) Inferential (turbine type),

(c) Electromagnetic,

(d) Positive displacement (integrating),

(e) fluid dynamic (vortex shedding),

(f) Anemometer,

(g) ultrasonic and

(h) Mass flowmeter (Coriolis).

Obstruction or head type flowmeters are of two types: differential pressure type and variable area type. Orifice meter, Venturimeter, Flow Nozzle and Pitot tube fall under the first category, while rotameter is of the second category. In all the cases, an obstruction is created in the flow passage and the pressure drop across the obstruction is related with the flow rate.

Basic Principle

It is well known that flow can be of two types: viscous and turbulent. Whether a flow is viscous or turbulent can be decided by the Reynold's number R_D. If $R_D > 2000$, the flow is turbulent. In the present case we will assume that the flow is turbulent, that is the normal case for practical situations. We consider the fluid flow through a closed channel of variable cross section, as shown in figure. The channel is of varying cross section and we consider two cross sections of the channel, 1 and 2. Let the pressure, velocity, cross sectional area and height above the datum be expressed as p1, v1, A1 and z1 for section 1 and the corresponding values for section 2 be p2, v2, A2 and z2 respectively. We also assume that the fluid flowing is incompressible. Now from Bernloulli's equation:

$$\frac{p_1}{\gamma} + \frac{v_1^2}{2g} + z_1 = \frac{p_2}{\gamma} + \frac{v_2^2}{2g} + z_2 \qquad (1)$$

where γ is the specific weight of the fluid.

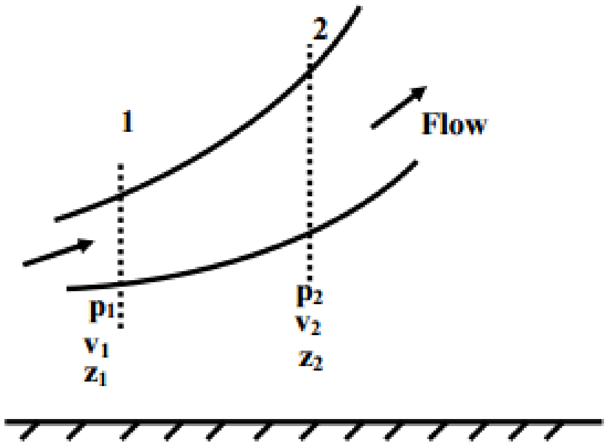


Fig. 1 Flow through a varying cross section

If $z_1=z_2$, then

$$\frac{p_1}{\gamma}+\frac{v_1^2}{2g}=\frac{p_2}{\gamma}+\frac{v_2^2}{2g} \quad (2)$$

If the fluid is incompressible, then $v_1A_1=v_2A_2$.
Therefore,

$$v_2^2-v_1^2=\frac{2g}{\gamma}(p_1-p_2)$$

or,

$$v_2^2(1-\frac{A_2^2}{A_1^2})=\frac{2g}{\gamma}(p_1-p_2)$$

Therefore,

$$v_2=\frac{1}{\sqrt{(1-\frac{A_2^2}{A_1^2})}}\sqrt{\frac{2g}{\gamma}(p_1-p_2)}=\frac{1}{\sqrt{1-\beta^4}}\sqrt{\frac{2g}{\gamma}(p_1-p_2)}$$

Considering circular cross section, we define β as the ratio of the two diameters, i.e.

$\beta=\frac{d_2}{d_1}$, and so, $\frac{A_2}{A_1}=\beta^2$.

Therefore, the volumetric flow rate through the channel can be expressed as:

$$Q=v_2A_2=\frac{A_2}{\sqrt{1-\beta^4}}\sqrt{\frac{2g}{\gamma}(p_1-p_2)} \quad (3)$$

From the above expression, we can infer that if there is an obstruction in the flow path that causes the variation of the cross sectional area inside the closed flow channel, there would be difference in static pressures at two points and by measuring the pressure difference, one can obtain the flow rate using eqn. (3). However, this expression is valid for incompressible fluids (i.e. liquids) only and the relationship between the volumetric flow rate and pressure difference is nonlinear. A special signal conditioning circuit, called square rooting circuit is to be used for getting a linear relationship.

Orifice meter

Depending on the type of obstruction, we can have different types of flow meters. Most common among them is the orifice type flowmeter, where an orifice plate is placed in the pipe line, as shown in figure. If d1 and d2 are the diameters of the pipe line and the orifice opening, then the flow rate can be obtained using eqn. (3) by measuring the pressure difference (p1-p2).

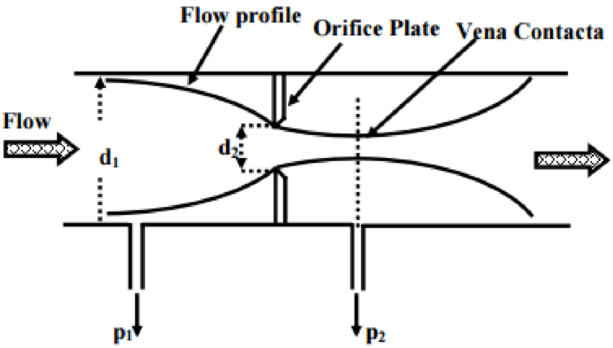


Fig. 2 Orifice type flowmeter

The flow expression obtained from eqn.(3) is not an accurate expression in the actual case, and some correction factor, named as discharge co-efficient (Cd) has to be incorporated in (3), as

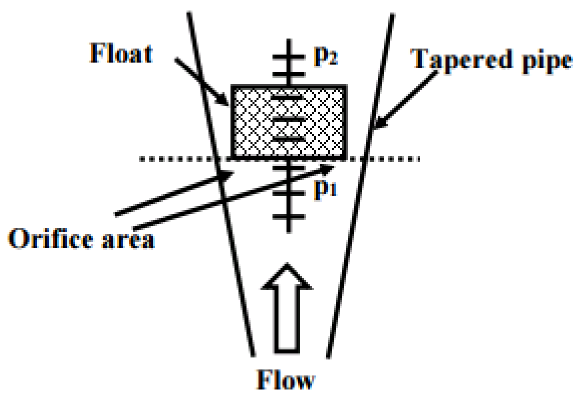
$$Q = v_2 A_2 = \frac{C_d A_2}{\sqrt{1-\beta^4}} \sqrt{\frac{2g}{\gamma}(p_1 - p_2)} \qquad (4)$$

C_d is defined as the ratio of the actual flow and the ideal flow and is always less than one. There are in fact two main reasons due to which the actual flow rate is less than the ideal one (obtained from eqn. (3)). The first is that the assumption of frictionless flow is not always valid. The amount of friction depends on the Reynold's number (R_D). The more important point is that, the minimum flow area is not the orifice area A_2, but is somewhat less and it occurs at a distance from the orifice plate, known as the Vena Contracta, and we are taking a pressure tapping around that point in order to obtain the maximum pressure drop. As a result, the correction factor C_d <1. In fact C_d depends on β, as well as on R_D. But it has been observed that for R_D>10^4 , the flow is totally turbulent and C_d is independent on R_D. In this range, the typical value of C_d for orifice plate varies between 0.6 and 0.7.

Rotameter

The orificemeter, Venturimeter and flow nozzle work on the principle of constant area variable pressure drop. Here the area of obstruction is constant, and the pressure drop changes with flow rate. On the other hand Rotameter works as a constant pressure drop variable area meter. It can be only be used in a vertical pipeline. Its accuracy is also less (2%) compared to other types of flow meters. But the major advantages of rotameter are, it is simple in construction, ready to install and the flow rate can be directly seen on a calibrated scale, without the help of any other device, e.g. differential pressure sensor etc. Moreover, it is useful for a wide range of variation of flow rates (10:1).

The basic construction of a rotameter is shown in figure. It consists of a vertical pipe, tapered downward. The flow passes from the bottom to the top. There is cylindrical type metallic float inside the tube. The fluid flows upward through the gap between the tube and the float. As the float moves up or down there is a change in the gap, as a result changing the area of the orifice. In fact, the float settles down at a position, where the pressure drop across the orifice will create an upward thrust that will balance the downward force due to the gravity. The position of the float is calibrated with the flow rate.



Basic construction of a rotameter.

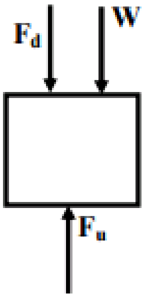
Let us consider,

γ_1 = Specific weight of the float
γ_2 = specific weight of the fluid
v_f = volume of the float
A_f = Area of the float.
A_t = Area of the tube at equilibrium (corresponding to the dotted line)

From equation (4), for incompressible fluid, we have, for the orifice,

$$Q = \frac{C_d A_2}{\sqrt{1-(\frac{A_2}{A_1})^2}} \sqrt{\frac{2g}{\gamma_2}(p_1 - p_2)} \qquad (7)$$

Now consider the free body diagram of the float, shown in fig. 8. Let,



Forces acting on the float

F_d = Downward thrust on the float

F_u = Upward thrust on the float

W = Apparent weight of the float

At balance,

$$W = F_u - F_d$$

or, $V_f(\gamma_1 - \gamma_2) = p_1 A_f - p_2 A_f$

Therefore,

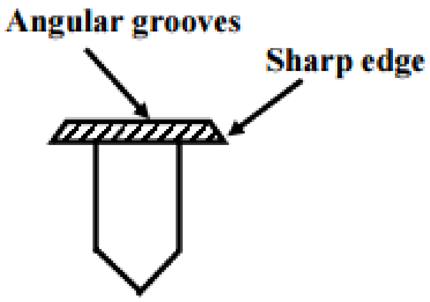
$$p_1 - p_2 = \frac{v_f}{A_f}(\gamma_1 - \gamma_2)$$

Substituting the above expression in (7), we obtain:

$$Q = \frac{C_d(A_t - A_f)}{\sqrt{1-\left\{\frac{A_t - A_f}{A_t}\right\}^2}} \left[\sqrt{\frac{2g}{\gamma_2}\frac{v_f}{A_f}(\gamma_1 - \gamma_2)}\right]$$

Construction of the float

The construction of the float decides heavily, the performance of the rotameter. In general, a float should be designed such that: (a) it must be held vertical (b) it should create uniform turbulence so as to make it insensitive to viscosity (c) it should make the rotameter least sensitive to the variation of the fluid density. A typical construction of the float is shown in figure. The top section of the float has a sharp edge and several angular grooves. The fluid passing through these grooves, causes the rotation of the float. The turbulence created in this process reduces the viscous force considerably.



Problem:

Apply the following specifications to size an orifice plate with corner tapings having an upstream pressure of 4bar and drop across orifice is 25mbar. Steam flow in 10.136 inches of steel pipe is 15 Tons/hr at temperature 200^{o}C with density 2.3587Kg/m^3

Solution:

Diameter if the pipe(D) = 10.136 inches

Flow rate (W) = 14 Tonns/hy

= 15 x 2205 Pounds/hr

= 33075 Pounds/hr

Differential pressure (h) = 250mbar

1 bar = 2089 psi

250 x 10^{-3} bar = 522.25psi

5.204 psi = 1 inch of water column

522.25 psi = (1/5.204) x 522.25 = 106.36 inches of water column

h = 106.36 inches of water column

Density = 2.3587Kg/m^3

10.02kg/m^3 = 1 pound / ft^3

2.3587Kg/m^3 = 0.147 pounds/ft^3

P_1 = 4 bar

= 4 x 14.5 = 58 psi

$$W = 359SD^2\sqrt{hr_f}$$

$$S = \frac{33075}{359(10.136)^2\sqrt{(100.36}}$$

= 0.234

From the sizing factor table, β = 0.60 for S= 0.234

B = d/D

d = 0.6 x 10.136 = 6.081

Orifice diameter = 6.081 inches

Problem:

Apply the following specifications to size an orifice plate with flange tapings having an upstream pressure of 9bar and drop across orifice is 250mbar. Gas flow in 2 inches of carbon steel pipe is 400Nm^3/hr at temperature 45^oC with density 10.9852Kg/m^3. Specific gravity 2.

Problem:

Apply the following specifications to design a rotameter. Pipe Diameter=2.5cm; Flowing liquid-water; Pressure drop=6500 pascal; Specific gravity of the float=4.7; Flow rate = $3.5x10^{-2}m^3$/min; C_d=0.68; Tube height=30cm; g=9.8m/sec^2

Pipe Diameter = 2.5cm;

Pipe radius (r_d) = 2.5/2 = 1.25cm

Radius of the float (r_f)= 0.9 r_d = 0.9 x 1.25 = 1.125cm

$A_f = \pi r_f^2$ = 3.14 x 1.125^2 = 3.976 cm^2

$V_f = A_f (P_2 – P_1) / (\rho_2-\rho_1)$

Specific gravity of the liquid = Density of liquid / Density of water

Specific gravity of the float = Density of float / Density of water

4.7 = Density of float / 1000kg/m^3

Density of float (ρ_2) = 4700 kg/m^3

= 4700/10^6 kg/cm^3

= 4.7 x 10^{-3} kg/cm^3

Flowing liquid-water

Density of water (ρ_1) = 1000 kg/m^3

= 1 x 10^{-3} kg/cm^3

Pressure drop=6500 pascal = $P_2 - P_1$

98.06KPa = 1 Kg/cm^2

98060 Pa = 1 Kg/cm^2

6500 Pa = (1/98060) x 6500 = 0.6629 Kg/cm^2

Specific gravity of the float=4.7; Flow rate = 3.5×10^{-2} m^3/min; C_d=0.68;

Tube height=30cm; g=9.8m/sec^2

$V_f = A_f (P_2 - P_1) / (\rho_2 - \rho_1)$

$= (3.976 \times 0.06629) / (4.7 - 1) \times 10^{-3} = 71.22 cm^3$

Flow rate (q) = 3.5×10^{-2} m^3/min;

$= 3.5 \times 10^{-2} \times 10^6$ cm^3/min = $(3.5 \times 10^{-2} \times 10^6)/60$ cm^3/sec

= 583.334 cm^3/sec

g=9.8m/sec^2 = 9.8×10^2 cm/sec^2

C_d=0.68;

Tube height (h) =30cm;

$$q = C_d\, 2\pi r_f h \tan\frac{\theta}{2}\sqrt{\frac{2g}{\rho_1}\frac{V_f(\rho_2-\rho_1)}{A_f}}$$

Substituting the values,

$$\tan\frac{\theta}{2} = 0.011218$$

$$\frac{\theta}{2} = \tan^{-1} 0.011218$$

Ans: $\boldsymbol{\theta = 1.284^o}$

Problem:

Use the following specifications to design a rotameter. Pipe Diameter=3.8cm; Flow rate = 80lpm; Pressure difference =40cm of water column; Specific gravity of the liquid=0.8; Specific gravity of the float=5.8; C_d=0.68; Tube height=10 inches g=9.8m/sec^2

Pipe Diameter = 3.8cm;

Pipe radius (r_d) = 3.8/2 = 1.9cm

Radius of the float (r_f)= 0.9 r_d = 0.9 x 1.9 = 1.71cm

$A_f = \pi r_f^2 = 3.14 \times 1.71^2 = 9.186$ cm^2

$V_f = A_f (P_2 - P_1) / (\rho_2 - \rho_1)$

Specific gravity of the liquid = Density of liquid / Density of water

Specific gravity of the float = Density of float / Density of water

5.8 = Density of float / 1000kg/m^3

Density of float (ρ_2) = 5.8 x 10^{-3} kg/cm^3

Density of liquid (ρ_1) = 0.8 x 10^{-3} kg/cm^3

Pressure difference =40cm of water column = $P_2 - P_1$

1 Kg/cm^2=10^{4}mm of water column

40cm of water column = $\frac{1}{10^4\, mm\ of\ \ water\ column} \cdot 400mm$

= 0.04 Kg/cm^2

$V_f = A_f (P_2 - P_1) / (\rho_2 - \rho_1)$

= (= 9.186 x 0.04) / (5.8-0.8) x 10^{-3} = 73.488cm^3

Tube height=10inches;

=10 x 2.54cm =25.4 cm

g=9.8m/sec^2

Flow rate (q) = 80lpm =0.08 m^3/min (1000lt=1m^3)

= 0.08 x 10^6 cm^3/min = (0.08 x 10^6)/60 cm^3/sec

= 1333.33 cm^3/sec

g=9.8m/sec^2 = 9.8 x 10^2 cm/sec^2

C_d=0.68;

$$q = C_d\, 2\pi r_f\, h \tan\frac{\theta}{2}\sqrt{\frac{2g}{\rho_1}\frac{V_f(\rho_2 - \rho_1)}{A_f}}$$

Substituting the values,

$$\tan\frac{\theta}{2} = 0.02293$$

$$\frac{\theta}{2} = \tan^{-1} 0.02293$$

Ans: ***θ = 2.628154º***

Resistance-Temperature Detector (RTD)

A resistance-temperature detector (RTD) is a temperature sensor that is based on the principles that the metal resistance changes with temperature. Metals used in these devices vary from **platinum**, which is very repeatable, quite sensitive, and very expensive, to **nickel**, which is not quite as repeatable, more sensitive, and **Copper** is less expensive.

Sensitivity of RTD is fractional change in resistance with temperature. For platinum, this number is typically on the order of 0.004Ω/°C . , and for nickel a typical value is 0.005Ω/°C. Thus, with platinum, for example, a change of only 0.4Ωwould be expected for a 100Ω RTD if the temperature is changed by 1°C.

Construction

An RTD is simply a length of wire whose resistance is to be monitored as a function of temperature. The construction is typically such that the wire is wound on a form (in a coil) to achieve small size and improve thermal conductivity to decrease response time. In many cases, the coil is protected from the environment by a sheath or protective tube.

Dissipation Constant

As the RTD is a resistance, there is an (I^2R) power dissipated by the device itself that causes a slight heating effect, a self-heating. This may also cause an erroneous reading or even upset the environment in delicate measurement conditions. Thus, the current through the RTD must be kept sufficiently low and constant to avoid self-heating. Typically, a dissipation constant is provided in RTD specifications. This number relates the power required to raise the RTD temperature by one degree of temperature. Thus, a 25mW/^{o}C dissipation constant shows that if power losses in the RTD equal 25 mW, the RTD will be heated by 1 ^{o}C .

The self-heating temperature rise can be found from the power dissipated by the RTD, and the dissipation constant from

$$\Delta T = \frac{P}{P_D}$$

Where, ΔT= temperature rise because of self-heating in°C

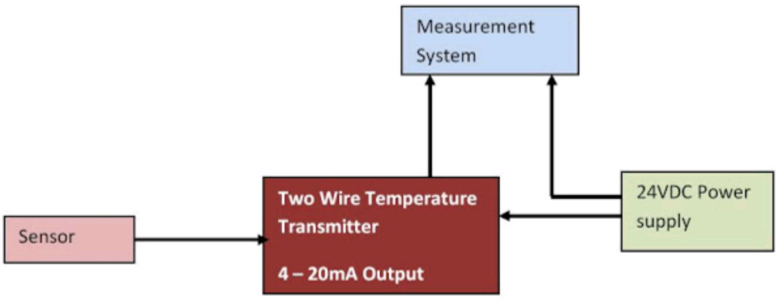
P= power dissipated in the RTD from the circuit in W

P_D = dissipation constant of the RTD in W/°C

TEMPERATURE TRANSMITTERS

A temperature transmitter converts the signals from thermocouple or RTD to a 4-20mA output signal and is the ideal solution for many remote temperature measurement applications. 4-20ma transmitters have definite advantages over conventional temperature measuring devices. In many cases, the temperature of a remote process must be monitored. Common temperature sensing devices such as thermocouples and RTDs produce signals of very low amplitude. These sensors can be connected to a two-wire transmitter that will amplify and condition the small signal. Once conditioned to a usable level, this signal can be transmitted through ordinary copper wire and used to drive other equipment such as meters, data loggers, chart recorders, computers or controllers.

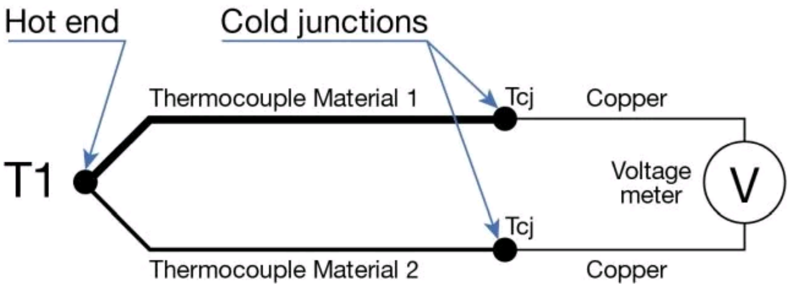
Specifically, a thermocouple input transmitter will draw 4 mA of current from a dc power supply when measuring the lowest temperature of the process. Hence this 4mA is called as the ***zero*** of the transmitter. Then, as the temperature rises, the thermocouple transmitter will draw proportionally more current, until it reaches 20 mA. This 20 mA signal corresponds to the thermocouple's highest sensed temperature. The range of current signal ie. 20mA – 4mA = 16mA is called as the ***span*** of the temperature transmitter. The zero is an offset adjustment and span is a sensitivity adjustment. The transmitter's internal signal-conditioning circuitry (powered by a portion of the 4-20 mA current) determines the temperature range that the output current signal will represent.



THERMOCOUPLE AND COLD JUNCTION COMPENSATION CIRCUIT

Thermocouples are very common temperature sensors in process plants. They can be used to measure very high temperatures, much higher than with RTDs (Resistance temperature detector). The thermocouple is also a very robust sensor, so it does not break easily. Although thermocouples are not as accurate as RTD sensors, they are accurate enough in many applications. Thermocouples are also relatively cheap sensors and as the the thermocouple is an active device its measurement circuit does not require excitation source like an RTD circuit does, so the circuit is more simple to make. There are many different thermocouple types available for different applications.

A thermocouple consists of two wires made of different electrical conductors that are connected together at one end (the "hot" end), that is the end is used to measure the temperature. Acording to Seebeck, when the connection point of two different metal wires are kept at different temperatures, there will be a thermo-electric current generated, causing a small voltage between the wires in the open end. The voltage depends on temperature and on the materials of the wires being used. This effect was named as Seebeck effect.



In the above picture, the Thermocouple material 1 and 2 represent the two different materials the thermocouple is made of. T1 is the hot end of the thermocouple, i.e. the point that is used to measure temperature. The two Tcj are the temperatures of the cold junctions.

There are many types of thermocouples being manufactured from different materials and alloys. Different materials will cause different sensitivity, different amount of thermovoltage being generated at the same temperature. Several thermocouple types have been standardized and names are given for specified materials being used. Names are such as type K, R, S, J, K, etc. Some of the most common thermocouples and their materials are listed in the below table:

Type	Materials[a]	Normal Range
J	Iron-constantan[b]	−190°C to 760°C
T	Copper-constantan	−200°C to 371°C
K	Chromel-alumel	−190°C to 1260°C
E	Chromel-constantan	−100°C to 1260°C
S	90% platinum + 10% rhodium-platinum	0°C to 1482°C
R	87% platinum + 13% rhodium-platinum	0°C to 1482°C

Disadvantages of thermocouple:

(i) Nonlinear

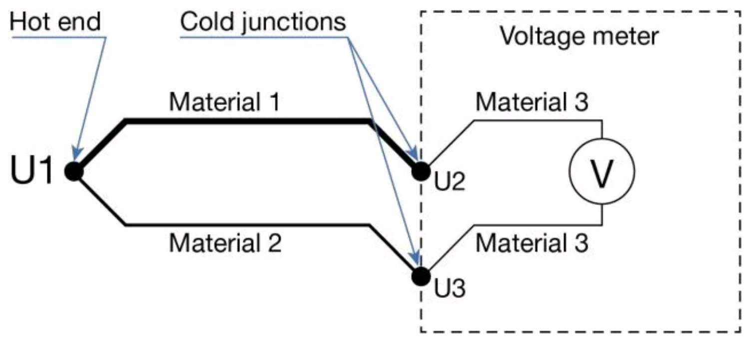
(ii) Reference is required

Signal Conditioning

The output voltage is very small of thermocouples is typically less than 50 mV. This means that considerable amplification will be necessary for practical application. In addition, the small signal levels make the devices susceptible to electrical noise. In most cases, the thermocouple is used with a high-gain differential amplifier.

Cold Junction Compensation:

While measuring the voltage of the thermocouple, the thermocouple wires are connected to a multimeter. But the multimeter connection material is typically copper or other metal so it is a different material than the thermocouple material, meaning we are creating two new thermocouples in the multimeter connections. Cow consider the following figure.



In the above picture, the material 1 and material 2 are the two thermocouple materials that form the thermocouple. The "hot end" is the point where they are welded together and that is the point that measures process temperature, this is where the voltage U1 is generated. This U1 is what we want to measure. In the "cold junction" points, the thermocouple is connected to the voltage meter that has connections made of different material, material 3. In these connections, thermovoltage U2 and U3 are being generated. It is these U2 and U3 voltages that we do not want to measure so we want to get rid of them. We have to eliminate or compensate for the thermocouples created in the cold junctions.

As the thermocouple voltage is proportional to the difference between the measurement and reference junction temperatures, variations of the reference temperature show errors in the measurement of temperature. The following techniques are employed for reference junction compensation:

1. Controlled temperature reference block

   In some cases, particularly when many thermocouples are in use, extension wires bring all reference junctions to a temperature-controlled box in the control room. Then, a local control system maintains this box at a precisely controlled temperature so that the reference is regulated. Readouts of temperature from the TC voltage take into account this known reference temperature.

2. Reference compensation circuits

The modern approach to reference correction is supplied by specialized integrated circuits (ICs) that add or subtract the correction factor directly to the TC output. These ICs, which are called cold junction compensators or ice point compensators, are actually temperature sensors themselves that measure the reference junction temperature. The ICs include circuitry that provides a scaled correction voltage, depending on the type of TC being used. Figure 11 shows a block diagram of how the compensator is used. The actual reference junctions are at the connection to the IC, so the IC temperature is the reference temperature.

3. Software reference correction

   In computer-based measurement systems, the reference junction temperature can be measured by a precision thermistor or another IC temperature sensor and provided as an input to the computer. Software routines then can provide necessary corrections to the thermocouple temperature signal that is also an input to the computer.

Need for cold junction compensation:

Cold Junction Compensation becomes necessary because the junction between each end of the thermocouple and the measuring system (connector block, terminal block) also adds a potential difference to the thermocouple voltage. To compensate for this added potential the temperature at the junction between the thermocouple and the measuring system should be known. This temperature is measured using some other temperature sensor other than a thermocouple; commonly used sensors are RTD, IC (integrated circuit) sensors and thermistors.

Pressure:

Pressure is the result of force applied onto a unit of area.

In the case of fluid and gas, this area would be the inside of a pipe, tank, vessel or other sealed housing. Since pressure is a physical quantity, it can be measured. Pressure is measured in one of the following five units.

– Pascal

– Bar

– Standard atmosphere or atm

– Torr

– Pounds per square inch or psi

Differential Pressure Transmitter (DPT)

A DPT is a pressure-measuring gauge or an electrical device that uses two elements to measure the differences of pressure in a sealed container such as a pipe. DP transmitters will have

– A primary element

– A secondary element

– An electronics housing

The primary element will produce a difference in pressure as the flow in the pipe increases. Different types of primary elements include

– Orifice plates

– Venturi tubes

– Pitot tubes

– Flow nozzles

– Laminar flow elements

– Wedge elements

The secondary element will measure the difference of pressure produced by the primary element as accurately as possible.

The elements in a DP transmitter will have sealed diaphragms and one of several ways to convert the pressure applied onto the diaphragms into an electrical signal. The current output is commonly a 4-20 milliamp signal, or in some cases a 0 to 5 or a 0 to 10 volt signal. The electrical output generated by the DP transmitter electronic module is linear and proportional to the actual measured differential pressure. Depending on the range of measured pressure, a 4 milliamp signal would equal a measured differential pressure of 0 psi and a 20 milliamp signal would equal the maximum measurable value. In this case, say that the maximum for example 100 psi. Using these variables, we would know that a 12 milliamp signal would equal 50 psi differential pressure. The relationship of the produced electrical signal to the units of measure is called the scaled output.

Working Principle:

Any difference of **pressure** across the cell causes the diaphragm to flex in the direction of least **pressure**. The sensing diaphragm is a precision-manufactured spring element, meaning that its displacement is a predictable function of applied force.

Zero adjustment in Differential Pressure Transmitter

There are two adjustments in Differential Pressure transmitter, namely ZERO and SPAN adjustment. For example, if we calibrate the transmitter for 4 to 20 mA with the range of 3 psi to 15 psi for 3 psi we must get 4 mA and if it not 4 mA(say 4.6 mA) means, we start to adjust the zero adjustment to make 4 mA for 3 psi and for 15 psi we must get 20 mA and if it not 20 mA (say 19.88 mA) means, we start to adjust the span to 20 mA. This is the way to calibrate the transmitter with the help of zero and span adjustment. The zero adjustment is used to produce a parallel shift of the input-output curve.

Problem:

Make use of the following specification to design a temperature transmitter using thermocouple. Input temperature: 0-90^{o}C. Temperature sensor T- type thermocouple. Sensitivity of the thermocouple = 42µV/^{o}C

Solution:

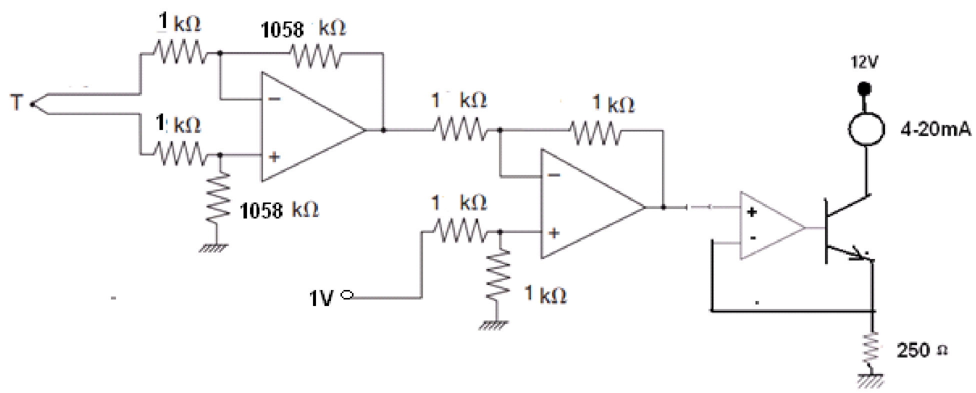
Sensitivity of the thermocouple = 42µV/^{o}C

At 90^o C thermocouple output = 90 x 42µV/^{o}C =3.78mV

To get output of 0 – 4V, required gain = (4/3.78 x 10^{-3})

= 1058

One possible solution is



Problem:

Develop a signal conditioning circuit for measuring temperature from 40°C to 100°C. It is required to produce 0 to 2V with RTD as temperature sensor. The sensitivity of the RTD is 0.004ohms/°C. The maximum current through RTD is 25mA.

The resistance of RTD can be founded by the following equation

$$R_t = R_0(1+\alpha t) \qquad (1)$$

Where R_t is the resistance of RTD at t˚C

R_o is the resistence of RTD at 0˚C

α is the resistance temperature coefficient in /˚C =0.004/˚C

Using the above equation (1) we have founded out the

Resistance of Pt-100 at 40˚C = R_{40} = 116 Ω

Resistance of Pt-100 at 100˚C = R_{90} = 140Ω

The maximum current through RTD is 25mA

Voltage drop across R_{100} with I_M= $I_M * R_{100}$

= 25x 10^{-3} * 140

= 3.5 V

$$R_2 = \frac{(V_{in} - I_m R_{100})}{I_m}$$

$$= \frac{(5-3.5)}{25mA}$$

$$= 60\Omega$$

Choose standard value of R_2 as = 100Ω, To null the bridge at 40˚C,

choose R_2 = R_3 = 100 Ω and R_1 = 116Ω =R_4

The bridge output voltage at 40˚C = 0V

Bridge output voltage at 100˚C = V_{100} = 2.68-2.91= 0.2366

Since we want 2 volts at the output of second stage at 100˚C,

Gain of second stage amplifier,

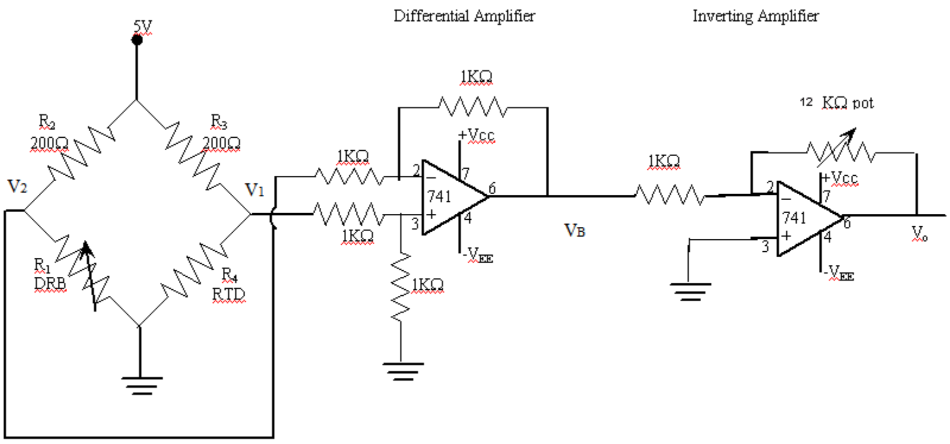
G = 2V / V_{100} = 8.45

Input the bridge output voltage to single op-amp differential amplifier.

Use a inverting op-amp circuit as the amplifier to give a gain of 8.45.

Inverting amplifier gain = -R_f/ R_1 = G = 8.45 , Choose R_1 = 1 K Ω, R_f = 8.45 KΩ, A

10K Ω pot can be used in forward path to set this gain.



Problem:

Design a signal conditioning circuit to measurement 50°C to 80°C and is to be converted into 0 to 2.0 V. RTD is used for measuring temperature with α 0.004Ω/°C and P_D=30mW/°C

Solution:

$$\text{At } 50°\text{C}, \ \text{RTD} = 150[1 + 0.004(50 - 65)] = 141\ \Omega$$
$$\text{At } 80°\text{C}, \ \text{RTD} = 150[1 + 0.004(80 - 65)] = 159\ \Omega$$

For a 1°C error because of self-heating, we can now find the maximum current through the RTD.

$P = P_D \times \Delta T$ = (30 mW°C) (1°C) = 30 mW

$I = [P/R]^{1/2} = [30 \text{ mW}/159\ ]^{1/2}$

= 13.7 mA

The bridge will be excited from a 5.0-V source, because this value is common. We will use the RTD as R_4 . The value of R_2 is determined by the requirement that the current be below 13.7 mA. The voltage across the RTD at will be

V = IR = (13.7 mA) (159Ω) = 2.17 V

R2 = (5 - 2.17)/13.7 mA = 206.5 Ω == 220Ω

$$\text{At } 50°\text{C}, \Delta V = 5\frac{141}{220 + 141} - 5\frac{141}{220 + 141}$$

$$\Delta V = 0 \text{ (just as designed)}$$

$$\text{At } 80°\text{C}, \Delta V = 5\frac{159}{220 + 159} - 5\frac{141}{220 + 141}$$

$$\Delta V = 0.1447 \text{ V}$$

All we need now is an amplifier to boost the voltage to 2.0 V at 80^{o}C

The required gain = (20/0.1447) = 13.8

For Non invertinf amplifier, R1=10KΩ an Rf=12.8KΩ